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Soil acidity effects on nutrient use efficiency in exotic maize genotypes

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Abstract

Maize (*Zea mays* L.) is the third most important cereal grown in the world. In South and Central America, maize is mostly grown on acidic soils. On these soils, yields are limited by deficient levels of available P, Ca, and Mg, and toxic levels of Al and Mn. A greenhouse study was conducted with 22 maize genotypes originating from Africa, Europe, and North, Central, and South America on acid, dark red latosol (Typic Haplorthox) at 2%, 41%, and 64% Al saturation at corresponding pH of 5.6, 4.5, and 4.3. With increasing Al levels, the nutrient efficiency ratios (NER = mgs of dry shoot weight / mg of element in shoot) for K, Ca and Mg increased, and NER for P and Zn tended to decrease. Overall, Al-tolerant genotypes produced higher shoot and root weight and had higher NER for P, Ca Mg, and Fe at 41% Al saturation. Genotypes used in this study showed genetic diversity for growth and NER of essential nutrients. It was concluded that selection of acid-soil-tolerant genotypes and further breeding of acid-soil-tolerant maize cultivars are feasible.

Introduction

The majority of tropical soils are acidic, contain high levels of toxic Al or Mn, and are deficient in available N, P, Ca, Mg, Zn, Mo, and Fe. Reduction in maize yields on such soils is due extensively to toxicity of Al and Mn and deficiency of P, Ca and Mg (Fageria et al., 1988; Foy, 1984). Aluminium toxicity is a serious problem in subsoils, which are difficult to amend with lime. In addition, liming subsoils is prohibitively expensive. Roots in limed soils tend to be confined to surface layers due to subsurface acidity (Al toxicity), which restricts the ability of plants to explore a larger soil volume for water and nutrients, and leads to reduced yields.

Inter- and intra-specific plant differences for tolerance to soil acidity/Al toxicity have been reported (Foy, 1984). Differences in yield and nutrient uptake have been related to root development (elongation and absorption), translocation, and shoot demand per unit of nutrient absorbed (Baligar et al., 1993a; Fageria et al., 1990; Foy, 1984). Cultivars with a high nutrient efficiency ratio (NER = mgs dry shoot weight / mg of element in shoot), when grown under acid soil stress, may have an advantage in adapting to mineral-stressed acid soils of the tropics, and genotypes that are efficient nutrient utilizers might be useful in breeding for more efficient cultivars for mineral-stressed ecosystems.

Genotypic differences for tolerance to soil acidity/Al toxicity among hybrids, open-pollinated populations, and inbreds of maize have been reported (Magnavaca et al., 1987a, b; Naspolini et al., 1981; Pandey and Gardner, 1992).

In the current study, 22 maize genotypes, originating in diversified ecosystems of the world, were evaluated at three levels of soil Al saturation (2%, 41%, 64% corresponding pH of 5.6, 4.5, and 4.3) under greenhouse conditions for growth and nutrient use efficiency ratios of essential elements.

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Materials and methods

Twenty-two maize genotypes originating in Africa, Bolivia, Brazil, Colombia, France, Mexico, former Yugoslavia, Puerto Rico, and USA were selected for the study (Table 1).

A dark red latosol (Typic Haplorthox) was collected under Cerrado vegetation at Sete Lagoas, MG, Brazil. The soil was obtained from the top 15 cm, air-dried, and screened through a 2-mm sieve. Details of experimental methods and soil chemical characteristics are given elsewhere (Baligar et al., 1993a). The unamended soil had pH of4.3 (1 soil : 1 water) and 1.98, 0.80, 0.15, and 0.18 (cmolc kg^{-1}), respectively, for exchangeable Al, Ca, Mg, and K. The exchangeable cations were determined by extracting soil by unbuffered 1 M KCl. The soil had 5.73% organic matter and 4.3 $\mu g\ g^{-1}$ of P (Bray-1). The unamended soil had 64% Al saturation. Aluminum saturation is calculated by dividing exchangeable Al by summation of exchangeable Ca, Mg, K, and Al and multiplying by 100, and ions are expressed at $cmol_c\ kg^{-1}$ of soil. Two additional Al saturations, 41% and 2%, with pH of 4.5 and 5.6, were achieved by the addition of dolomitic lime (54.9% CaO, 19.6% MgO, 125.1% of neutralization). All Al treatments received 70, 75, and 95 $\mu g\ g^{-1}$ of N, P, and K, respectively, as NH_4NO_3, and KH_2PO_4, and 5 $\mu g\ g^{-1}$ Zn, as $ZnSO_4 \cdot 7H_2O$.

Rectangular boxes (90 × 30 × 16 cm) were filled with 20 kg soil. Soil moisture was maintained at 60% of 33 kPa tension during growth. In each box, dividers were used to make five subdivisions. Ten seeds of a given genotype were planted to each section, and stands were thinned to five plants per section 10 days after planting and grown in a greenhouse (28 °C day/22 °C night) during November and December. Soil Al saturations were randomly assigned as main plots, and genotypes as subplots with three replications. The experiment was terminated 28 days after planting, and shoots and roots were separated. Roots were washed free of soil, and shoots and roots dried in a forced-air oven for one week at 60 °C and weighed. Details of plant elemental analysis are given elsewhere (Baligar et al., 1993a).

Table 1. Maize genotypes used in the study

Number	Origin	Pedigree
1	Puerto Rico, USA	Gut. 129A-528/548 34/71
2	Mexico	Tuxpan 49953
3	Mexico	Tuxpan 54253
4	Colombia	Cateto Colombia 26970
5	Colombia	Cateto Colombia 9671
6	Central America	Asteca 161
7	Central America	Asteca A
8	Brazil	IAC - Mesclado
9	Brazil	51b X 52b-51-53
10	Brazil	XL45 X 1020
11	Brazil	SLP 179-71
12	Brazil	Save 135B 127/71
13	Bolivia	Cateto Boliviano 35269
14	Bolivia	Cateto Boliviano 26670
15	France	Armour 48-MS-Cruz 48/40/7
16	France	Cenargen 1278/1516 ZPL-180
17	Yugoslavia	ZPSC3 1243/1481
18	Yugoslavia	ZP719 1250/1488
19	South Africa	Pop South African L-700
20	South Africa	Pop South African L-708
21	Africa	African Inbred Line 15950
22	Africa	African Inbred Line 23360

Results and discussion

In general, increase in soil Al saturation from 2 to 41% tended to improve overall dry matter accumulation in maize shoots and roots, but further increases in Al saturation to 64% reduced dry matter of both shoots and roots (Table 2). Shoot and root growth of all entries was

Table 2. Growth and nutrient efficiency ratios for essential elements in maize genotypes as influenced by levels of soil Al saturation

Parameters	Soil-Al saturation (%)			
	2 (pH 5.6)	41 (pH 4.5)	64 (pH 4.3)	LSD (0.05)
Shoot dry weight (g/plant)	0.15	0.16	0.10	0.04
Root dry weight (g/plant)	0.06	0.08	0.04	0.02
Shoot/root dry weight ratio	2.53	2.13	2.21	0.53
Nutrient-efficiency ratio (NER)[a]				
P	368	384	256	52.0
K	19	25	35	5.0
Ca	158	179	304	31.0
Mg	332	400	531	58.0
Zn	16.4	9.5	9.8	2.6
Fe	3.5	3.0	3.7	0.8

[a] NER = mgs shoots dry weight mg^{-1} of element in shoot, multiply by 10^3 for Zn, Fe.

Table 3. The nutrient efficiency ratios (NER) of most efficient (E) and most inefficient (I) maize genotypes grown at 2% and 41% of soil Al saturation

Element	Efficiency	Genotype	NER[a]	Al tolerance[b]
2% Al Saturation, pH 5.6				
P	E	16 Cenargen 1278/1516 ZPL-180	555.6	MT
	I	2 Tuxpan 49953	172.4	S
K	E	14 Cateto Bolivanio 26770	25.2	T
	I	22 African Inbred Line 23360	13.8	MT
Ca	E	17 ZPSC3 1243/1481	204.1	T
	I	4 Cateto Columbia 26970	90.9	S
Mg	E	17 ZPSC3 1243/1481	370.4	T
	I	2 Tuxpan 49953	250.0	S
Zn	E	8 IAC - Mesclado	25.0	MT
	I	6 Asteca 161	8.3	S
Fe	E	12 Save 135B 127/71	5.8	MT
	I	2 Tuxpan 49953	1.4	S
41% Al Saturation, pH 4.5				
P	E	16 Cenergen 1278/1516 ZPL-180	625.0	MT
	I	2 Tuxpan 49953	161.3	S
K	E	21 African Inbred Line 15950	45.6	S
	I	16 Cenergen 1278/1516 ZPL-180	17.6	MT
Ca	E	2 Tuxpan 49953	256.4	S
	I	21 African Inbred Line 15950	114.9	S
Mg	E	17 ZPSC3 1243/1481	476.2	T
	I	11 SLP 179/71	333.3	MT
Zn	E	20 Pop South African L-708	16.1	S
	I	11 SLP 179/71	6.2	MT
Fe	E	16 Cenargen 1278/1516 ZPL-180	4.9	MT
	I	6 Asteca 161	1.3	S

[a] NER for Zn and Fe, multiply by 10^3.
[b] Al tolerance ranking is based on shoot growth at 41% Al saturation. S = sensitive, MT = moderately tolerant, T = tolerant.

influenced by the presence or absence of phytotoxic levels of Al in the growth medium.

Maize genotypes were classified into efficient and inefficient utilizers of absorbed nutrients according to NER. In acid soils, levels of plant-available Ca, Mg, P, and micronutrients are limited, and at the same time, Al toxicity restricts root growth, thereby hindering plant ability to explore large soil volumes to acquire these essential elements. Maize genotypes that have high NER for essential nutrients might be able to perform well in acidic, infertile soil. In the current study, the NER among maize genotypes for essential nutrients differed depending upon level of Al toxicity (Table 2). Increasing Al increased NER for K, Ca, and Mg and reduced NER for P and Zn.

The level of Al in saturation in the soil also influenced the most efficient (E) and most inefficient (I) genotypes for NER of various nutrients (Table 3). At 2% Al saturation, the genotype Cenargen 1278/1516 ZPL-180 (France) was very efficient in utilization of P, and genotype ZPSC3 1243/1481 (Yugoslavia) was very efficient in utilization of Ca and Mg. Genotypes Cateto Boliviano 26770 (Bolivia), IAC-Mesclado (Brazil), and Save 135B 127/71 (Brazil) were very efficient in utilization of absorbed K, Zn, and Fe, respectively. Genotype Tuxpan 49953 (Mexico) was very inefficient in utilization of P, Mg, and Fe.

At 41% of soil Al saturation, genotype Cenargen 1278/1516 ZPL-180 was very efficient in utilization of P and Fe and inefficient in utilization of K (Table 3). Genotype ZPSC3 1243/1481 was very efficient in

Table 4. Average values for shoot and root growth and nutrient efficiency ratios (NER) by Al-sensitive and Al-tolerant maize genotypes grown at 41% soil aluminium saturation

Parameters	Maize genotype[a]		
	Al-sensitive	Al-tolerant	LSD (0.05)
Growth			
Shoot dry weight (g/plant)	0.07	0.27	0.03
Root dry weight (g/plant)	0.04	0.11	0.02
Shoot/root	1.90	2.60	0.50
NER[b]			
P	288	437	64
K	27	24	6
Ca	185	199	37
Mg	392	426	31
Zn	10	10	2
Fe	2	4	1

[a] Al-sensitive: Shoot dry weight $\leq$ 0.10 g/plant and includes genotypes 2, 3, 4, 6, 20, 21.
Al-tolerant: Shoot dry weight $\geq$ 0.23 g/plant and includes genotypes 1,10, 14, 17, 18, 19.
[b] NER for Zn and Fe, multiply by 10^3.

utilization of Mg. Genotype SLP 179/71 (Brazil) gave low NER for Mg and Zn. Genotype African inbred line 15950 had high NER for K and low NER for Ca. Based on shoot dry matter accumulation (data not shown), genotype Cenargen 1278/1516 ZPL-180 is moderately tolerant to soil Al; however, it had high NER for P in presence or absence of phytotoxic Al. Therefore, it might be used as a P-efficient gene donor in acid-soil-tolerance plant breeding programs. Genotypes used in this study showed intraspecific diversity in nutrient uptake efficiency in the presence or absence of phytotoxic Al in the growth medium. The presence of inter- and intra-specific variation in mineral uptake and utilization in various types of crop plants is well documented in the presence or absence of aluminium (Baligar et al., 1987, 1989a, b, 1993b; Foy, 1984).

Al-tolerant genotypes produced higher shoot and root dry matter than Al-sensitive genotypes (Table 4). Al-tolerant genotypes also had higher nutrient efficiency ratios for P, Ca, Mg, and Fe than Al-sensitive genotypes. Baligar et al. (1989a, 1993a and b) have also reported similar observations for exotic sorghum genotypes grown at varying soil-Al saturation.

Conclusions

Results show that Al-tolerant maize genotypes have great potential for increasing dry matter yields at phytotoxic Al levels in soils, partly because they have higher efficiency of utilization of absorbed essential nutrients, particularly P. Such intraspecific diversity in growth and nutrient use efficiency could be exploited in breeding programs to develop cultivars that have high tolerance to soil acidity. The greenhouse technique used appeared to be reliable for separating maize genotypes into Al-tolerant and -intolerant types.

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